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(54) ILLUMINATION OPTICAL APPARATUS, EXPOSURE APPARATUS INCLUDING THE SAME AND METHOD OF MANUFACTURING MICRO APPARATUS USING THE SAME

(57) ABSTRACT
The present invention provides an illumination optical apparatus for adjusting an illumination NA and a size of an illumination region formed in an illumination target surface to a desired value respectively while preferably reducing light loss. The present invention relates to the illumination optical apparatus for illuminating an illumination target surface. The illumination optical apparatus comprises a first variable magnification optical system 4 with a variable focal length or magnification for adjusting an illumination numerical aperture on the illumination target surface and a second variable magnification optical system 7 with a variable focal length or magnification for changing a size of the illumination region formed on the illumination target surface.

WHAT IS CLAIMED IS:

1. An illumination optical apparatus for illuminating an illumination target surface, comprising:
a first variable magnification optical system with a variable focal length or magnification for adjusting an illumination numerical aperture in the illumination target surface; and
a second variable magnification optical system with a variable focal length or magnification for changing a size of an illumination region formed on the illumination target surface.

2. The illumination optical apparatus according to claim 1, further comprising a regulating system for adjusting the focal length or the magnification of the first variable magnification optical system and the second variable magnification optical system in order to set the illumination numerical aperture and the size of the illumination region to a desired value, respectively.

3. The illumination optical apparatus according to claims 1 to 2, further comprising:
a light source means for supplying illumination light;
a multiple light source forming means for forming a number of light beams based on the illumination light; and
a light converting optical system for converting the light from the light source means into light with a predetermined cross-section,
wherein the first variable magnification optical system guides the light passing through the light converting optical system onto the multiple light source forming means, and the second variable magnification optical system guides the number of the light beams from the multiple light source forming means onto the illumination target surface.

4. The illumination optical apparatus according to claims 1 to 2, further comprising:
a light source means for supplying illumination light; and
a light converting optical system for converting the light from the light source means into light with a predetermined cross-section,
wherein the first variable magnification optical system guides the light from the light converting optical system to the second variable magnification optical system, and
the second variable magnification optical system comprises a multiple light source forming means for forming a number of light beams based on the light through the first variable magnification optical system and guides the light from the first variable magnification optical system onto the illumination target surface.

5. The exposure apparatus, comprising:
the illumination optical apparatus according to claims 1 to 4; and
a optical system for projection-exposing a pattern of a mask disposed on the illumination target surface onto a photosensitive substrate.

6. A method for manufacturing a micro device, comprising the steps of:
illuminating a mask disposed in the illumination target surface by the illumination optical

apparatus of the illumination optical apparatus according to claims 1 to 4; and
transferring a pattern of the illuminated mask on a photosensitive substrate.

7. An exposure apparatus having an illumination optical apparatus for illuminating a pattern of a mask having a predetermined pattern with light for exposure and a projection system for projection-exposing an image of the pattern of the mask on a photosensitive substrate, comprising:

an input means for inputting information under an exposure condition in the photosensitive substrate or an illumination condition in the mask,

wherein the illumination optical apparatus comprises:

a light converting means for converting the light for exposure into light having a desired light intensity distribution based on the input information from the input means;

a first variable magnification optical system that adjusts an illumination numerical aperture in the mask based on the input information from the input means; and

a second variable magnification optical system that changes the size of the illumination region formed on the mask based on the input information from the input means.

8. The exposure apparatus according to claim 7, further comprising:

an optical integrator for uniformly illuminating the mask,

wherein, the first variable magnification optical system is disposed at an incident side of the optical integrator; and

the second variable magnification optical system is disposed at an emitting side of the optical integrator.

9. A method for manufacturing a micro device comprising the steps of illuminating a pattern of a mask having a predetermined pattern with light for exposure and projection-exposing an image of the pattern of the mask on a photosensitive substrate,

wherein illuminating a pattern of mask comprises:

inputting information under an exposure condition in the photosensitive substrate or an illumination condition in the mask;

converting the light for exposure into light having a desired light intensity distribution based on the input information from the input process;

changing the size of the illumination region formed on the mask based on the input information from the input process; and

adjusting an illumination numerical aperture in the mask based on the input information from the input means.

10. The method according to claim 9, wherein the step of adjusting the illumination numerical aperture comprises correcting a value of the illumination numerical aperture changed by changing the size of an illumination region to substantially constantly maintain the value of the illumination numerical aperture.

11. An exposure apparatus having an illumination optical apparatus for illuminating a pattern of a mask having a predetermined pattern with light for exposure and a projection

system for projection-exposing an image of the pattern of the mask on a photosensitive substrate,

wherein the illumination optical apparatus comprises:

a light converting means for converting the light for exposure into light having a desired light intensity distribution based on the input information from the input means;

a first variable magnification optical system that adjusts an illumination numerical aperture in the mask based on the input information from the input means; and

a second variable magnification optical system that changes the size of the illumination region formed on the mask based on the input information from the input means.

12. The exposure apparatus according to claim 11, wherein the changing means comprises a light converting means for selectively converting the light for exposure into one of a plurality of light having different light intensity distributions.

13. The exposure apparatus according to claim 12, wherein the light converting means has a first diffraction optical member for forming a first light intensity distribution and a second diffraction optical member for forming a second light intensity distribution different from the first light intensity distribution,

wherein the second diffraction optical member is replaceable with the first diffraction optical member relative to an optical path.

14. A method for manufacturing a micro device comprising the steps of illuminating a pattern of a mask with a predetermined pattern using an illumination optical apparatus and projection-exposing an image of the pattern of the mask on a photosensitive substrate using a projection system,

wherein illuminating the pattern of the mask comprises:

changing light intensity distribution in a pupil position of the illumination optical apparatus or in the vicinity thereof; and

adjusting an illumination numerical aperture in the mask according to the change of the light intensity distribution by changing the light intensity distribution.

ILLUMINATION OPTICAL APPARATUS, EXPOSURE APPARATUS INCLUDING THE SAME AND METHOD OF MANUFACTURING MICRO APPARATUS USING THE SAME

Background of the Invention

Industrially Applicable Field

[0001] The present invention relates to an illumination optical apparatus and an exposure apparatus with the illumination optical apparatus. In particular, the present invention relates to an illumination optical apparatus suitable for an exposure apparatus for manufacturing a micro device such as a semiconductor element, an imaging element, a liquid crystal display element, and a thin film magnetic head by a photolithography process.

Background Arts

[0002] In such a typical exposure apparatus, light emitted from a light source enters into an optical integrator such as a micro fly's eye and forms a secondary light source, which consists of a number of light source images, in a rear focal plane thereof. The light from the secondary light source is restricted while passing through an aperture stop disposed in the vicinity thereof and then enters into a condenser lens. The aperture stop restricts a shape or size of the secondary light source to a desired shape or size according to a desired illumination condition (exposure condition). The light concentrated by the condenser lens forms a rectangular illumination region in a predetermined surface that conjugates with a mask. Mask blinds are disposed near the predetermined surface as illumination field stops.

[0003] Thus, the light from the rectangular illumination region formed in the predetermined surface is restricted through an illumination field stop and then passes through a relay lens to superposedly illuminate the mask with predetermined patterns formed thereon. Thus, images of openings of the illumination field stop are formed on the mask as a rectangular illumination region. The light passing through the pattern of the mask is imaged on a wafer through a projection optical system. In this way, the mask pattern is projection-exposed (transferred) on the wafer. The pattern formed in the mask is heavily concentrated; thus, in order to accurately transfer such a micro pattern on the wafer, it is necessary to form a uniform illuminance distribution on a wafer.

[0004] Attention has been made in recent years to a technology that changes the size of the opening (light transmitting portion) of the aperture stop disposed at an emitting side of an optical integrator to change the size of the secondary light source formed through the optical integrator, and thereby changing a coherency σ of illumination (σ value = a diameter of an aperture stop / a diameter of a pupil of a projection optical system, or σ value = a numerical aperture in an emitting side of an illumination optical system / a numerical aperture in an incident side of a projection optical system). Further, attention has been made to a technology wherein the shape of the opening of the aperture stop disposed at the emitting side

of the optical integrator is set to an annular shape or a shape with 4 holes (i.e., quadrupolar shape) to restrict the shape of the secondary light source formed by the optical integrator to an annular shape or a quadrupolar shape, and thereby enhancing the depth of focus or resolution of a projection optical system.

Problems to be resolved by the Invention

[0005] In an exposure apparatus, there may be a need to change a size of an illumination region, i.e., an exposure region, formed on a photosensitive substrate such as a wafer according to a characteristic of a micro device to be manufactured. In other words, there may be a need to change the size of the illumination region formed on the mask according to the characteristic of the mask to be used. For example, a method of reducing the size of an opening of an illumination field stop can be considered to form an illumination region that is smaller than a standard illumination region. However, in such a method, light loss occurs in an illumination field stop, thereby decreasing the throughput of an exposure apparatus.

[0006] Meanwhile, in order to substantially avoid light loss in an illumination field stop, for example, a method of changing the magnification of a relay lens to reduce the illumination region formed on a mask and further an exposure region formed on a photosensitive substrate can be also considered. However, in such a method, the illumination numerical aperture (hereinafter, "illumination NA") is changed and further the optimally designed σ value is changed according to the change in the size of the illumination region formed on a mask.

[0007] As such, there is a demand in an exposure apparatus that a σ value must be adjusted to a desired value to have the size of an exposure region according to the characteristic of a micro device to be manufactured. In other words, in an illumination optical apparatus for use with an exposure apparatus, there is a demand that the illumination NA must be adjusted to a desired value to have the size of an illumination region according to the characteristic of a mask to be used. In addition, a micro device, which is mentioned in the present invention, comprises a semiconductor element with such as semiconductor integrated circuits, a highly micro flat-panel display, an imaging element such as a CCD, a magnetic head for a personal computer hard disk, a diffraction optical element, etc.

[0008] Further, there is a problem in that when a light intensity distribution of a secondary light source formed by an optical integrator (a light intensity distribution formed in a pupil position of an illumination apparatus for exposure or in the vicinity thereof) is changed into a desired shape (for example, one of a circular shape, an annular shape, or a quadrupolar shape) or a desired size (for example, a size of a circular shape, an annular shape, or a quadrupolar shape) in order to change an exposure condition or an illumination condition, an illumination numerical aperture (NA) in a mask as an illumination target is changed and a preferable mask pattern cannot be exposed to a photosensitive substrate such as a wafer based on the desired exposure condition or illumination condition.

[0009] In view of the foregoing, it is an object of the present invention to provide an

illumination optical apparatus, an exposure apparatus with the illumination optical apparatus, and a method for manufacturing a micro device using the exposure apparatus that are capable of adjusting an illumination NA and a size of an illumination region formed in an illumination target surface to a desired value, respectively, while preferably suppressing the light loss.
It is a further object of the present invention to provide an exposure apparatus and a method for manufacturing a micro device that can preferably expose the mask pattern on a photosensitive substrate such as a wafer based on the desired exposure condition or a desired illumination condition even when an exposure condition or an illumination condition is changed.

Means for resolving the Problem

[0010] In order to accomplish the aforementioned objects, according to the first aspect of the present invention, there is provided an illumination optical apparatus for illuminating an illumination target surface. The illumination optical apparatus is characterized in that it has a first variable magnification optical system with a variable focal length or magnification for adjusting an illumination numerical aperture in the illumination target surface; and a second variable magnification optical system with a variable focal length or magnification for changing a size of an illumination region formed in the illumination target surface.

[0011] According to a preferable embodiment of the first aspect, in order to set the illumination numerical aperture and the size of the illumination region to a desired value respectively, it is preferred that the illumination optical apparatus has a regulating system for adjusting the focal length or the magnification of the first variable magnification optical system and the second variable magnification optical system.

[0012] Further, according to a preferred embodiment of the first aspect, it is preferred that the illumination optical apparatus has a light source means for supplying illumination light; a multiple light source forming means for forming a number of light beams based on the illumination light; and a light converting optical system for converting the light from the light source means into light with a predetermined cross-section, and wherein the first variable magnification optical system guides the light passing through the light converting optical system onto the multiple light source forming means and the second variable magnification optical system guides the number of the light beams from the multiple light source forming means onto the illumination target surface.

[0013] In this case, it is preferred that the multiple light source forming means has a wavefront-splitting type optical integrator; the first variable magnification optical system converts the divergence light formed through the light converting optical system into substantially parallel light to guide the light onto an incident surface of the wavefront-splitting type optical integrator; and the regulating system changes a focal length of the second variable magnification optical system in order to adjust the size of the illumination region formed in the illumination target surface to a desired value and changes a focal length

of the first variable magnification optical system in order to adjust the illumination numerical aperture that changed according to the change in the focal length of the second variable magnification optical system to a desired value.

[0014] Further, it is preferred that the multiple light source forming means has an internal reflection type optical integrator; the first variable magnification optical system concentrates a divergence light formed through the light converting optical system in the vicinity of the incident surface of the internal reflection type optical integrator; and the regulating system changes the magnification of the second variable power optical system in order to adjust the size of the illumination region that formed in the illumination target surface to a desired value, and changes the magnification of the first variable magnification optical system in order to adjust the illumination numerical aperture that changed according to the change in the magnification of the second variable magnification optical system to a desired value.

[0015] Further, according to a preferred embodiment of the first aspect, it is preferred that the illumination optical apparatus has a light source means for supplying illumination light and a light converting optical system for converting the light from the light source means into light with a predetermined cross-section shape, wherein the first variable magnification optical system guides the light from the light converting optical system to the second variable magnification optical system; and the second variable magnification optical system comprises a multiple light source forming means for forming a number of light beams based on the light through the first variable magnification optical system, and guides the light from the first variable magnification optical system onto the illumination target surface.

[0016] In this case, it is preferred that the multiple light source forming means has an optical integrator group comprising a plurality of wavefront-splitting type optical integrators movable along an optical axis and having a variable focal length; the first variable magnification optical system converts a divergence light formed through the light converting optical system into substantially parallel light to guide the light to an incident surface of the optical integrator group; and the regulating system changes a focal length of the optical integrator group in order to change only the size of the illumination region formed on the illumination target surface to adjust the size to a desired value, and changes a focal length of the first variable magnification optical system in order to change only the illumination numerical aperture to adjust the illumination numerical aperture to a desired value.

[0017] Further, in this case, it is preferred that the optical integrator group has, in order from the light source side, a first optical integrator movable along the optical axis and having a positive refracting power; a second optical integrator movable along the optical axis and having a negative refracting power; and a third optical integrator fixed relative to the optical axis and having a positive refracting power, wherein the regulating system moves the first optical integrator and the second optical integrator along the optical axis independently of each other in order to change the focal lengths continuously without moving the rear focal surface of the optical integrator group.

[0018] Further, according to a preferred embodiment of the first aspect, it is preferred that the light converting optical system has a plurality of diffraction optical elements configured to be freely inserted to and retracted from an illumination optical path; and the plurality of the diffraction optical elements convert the substantial parallel light from the light source means into the divergence light with a cross section different from one another.

[0019] Further, according to the second aspect of the present invention, there is provided an exposure apparatus having the illumination optical apparatus according the first aspect and a projection optical system for projection-exposing a pattern of a mask disposed on the illumination target surface onto a photosensitive substrate. In this case, it is preferred that the regulating system adjusts the focal length or the magnification of each of the first variable magnification optical system and the second variable magnification optical system based on the information on the pattern of the mask.

[0020] Further, according to the third aspect of the present invention, threre is provided a method for manufacturing a micro device comprising illuminating a mask disposed in the illumination target surface by the illumination optical apparatus of the first aspect and transferring a pattern of the illuminated mask on a photosensitive substrate. In this case, it is preferred that the method further comprises adjusting the focal length or the magnification of each of the first variable magnification optical system and the second variable magnification optical system based on the information on the pattern of the mask.

[0021] Further, in order to accomplish the other object, according to the fourth aspect of the present invention, there is provided an exposure apparatus that has an illumination optical apparatus for illuminating a pattern of a mask having a predetermined pattern with light for exposure; a projection system for projection-exposing an image of the pattern of the mask on a photosensitive substrate and an input means for inputting information under an exposure condition in the photosensitive substrate or an illumination condition in the mask, wherein the illumination optical apparatus comprises a light converting means for converting the light for exposure into light having a desired light intensity distribution based on the input information from the input means; a first variable magnification optical system that adjusts an illumination numerical aperture in the mask based on the input information from the input means; and a second variable magnification optical system that changes the size of an illumination region formed on the mask based on the input information from the input means. In this case, it is preferred that the illumination optical apparatus comprises an optical integrator for uniformly illuminating the mask; the first variable magnification optical system is disposed at an incident side of the optical integrator; and the second variable magnification optical system is disposed at an emitting side of the optical integrator.

[0022] Further, according to the fifth aspect of the present invention, there is provided a method for manufacturing a micro device comprising illuminating a pattern of a mask having a predetermined pattern with light for exposure and projection-exposing an image of the pattern of the mask on a photosensitive substrate, wherein illuminating a pattern of mask comprises inputting an information on an exposure condition in the photosensitive substrate

or an illumination condition in the mask; converting the light for exposure into light having a desired light intensity distribution based on the input information from the input process; changing the size of an illumination region formed in the mask based on the input information from the input process; and adjusting an illumination numerical aperture in the mask based on the input information from the input means. In this case, it is preferred that adjusting the illumination numerical aperture comprises correcting a value of the illumination numerical aperture that changed by changing the size of an illumination region to substantially constantly maintain the value of the illumination numerical aperture.

[0023] Further, according to the sixth aspect of the present invention, there is provided an exposure apparatus having an illumination optical apparatus that illuminates a pattern of a mask with a predetermined pattern by light for exposure and a projection system that projection-exposes an image of the pattern of the mask on a photosensitive substrate, wherein the illumination optical apparatus has a changing means for changing an light intensity distribution in a pupil position of the illumination optical apparatus or in the vicinity thereof and an adjusting means for adjusting an illumination numerical aperture in the mask according to the change of the light intensity distribution by the changing means. In this case, it is preferred that the changing means comprises a light converting means for selectively converting the light for exposure into one of a plurality of light having different light intensity distributions. Further, in this case, it is preferred that the light converting means has a first diffraction optical member for forming a first light intensity distribution; and a second diffraction optical member for forming a second light intensity distribution different from the first light intensity distribution, whrerein the second diffraction optical member is replaceable with the first diffraction optical member relative to an optical path.

[0024] Further, according to the seventh invention of the present invention, there is provided a method for manufacturing a micro device comprising illuminating a pattern of a mask with a predetermined pattern using an illumination optical apparatus and projection-exposing an image of the pattern of the mask on a photosensitive substrate using a projection system,wherein illuminating the pattern of the mask comprises changing a light intensity distribution in a pupil position of the illumination optical apparatus or in the vicinity thereof; and adjusting an illumination numerical aperture in the mask according to the change of the light intensity distribution by changing the light intensity distribution.

Embodiments

[0025] The present invention has a first variable magnification optical system for adjusting an illumination NA in an illumination target surface and a second variable magnification optical system for changing a size of an illumination region formed in the illumination target surface. Further, in an exemplary embodiment of the present invention, there is provided a light converting optical system for converting light from a light source means into divergence light with a predetermined cross-section shape, and the first variable magnification optical system condenses such divergence light and guides it onto an incident surface of a multiple light source forming means, and the second variable magnification optical system condenses

light from the multiple light source forming means and guides it onto the illumination target surface.

[0026] Specifically, in case of using a wavefront-splitting type optical integrator such as a micro fly's eye or a fly's eye lens as the multiple light source forming means, the first variable magnification optical system converts the divergence light formed through the light converting optical system into substantially parallel light and guides it to an incident surface of the optical integrator. The second variable magnification optical system condenses light from a secondary light source formed in a rear focal surface of the optical integrator and guides it to the illumination target surface. In this case, the shape of each lens element (or micro lens) constituting a micro fly's eye or a fly's eye lens differs from the shape of an illumination region formed in the illumination target surface. Further, their sizes depend upon a focal length of the second variable magnification optical system.

[0027] Thus, if the focal length of the second variable magnification optical system is changed, the size of the illumination region formed in the illumination target surface is changed and the illumination NA in the illumination target surface is also changed. On the other hand, if the focal length of the first variable magnification optical system is changed, a size of an illumination region formed in the incident surface of the optical integrator is changed, thereby only the illumination NA is changed without any change in the size of the illumination region. In this way, by changing the focal length of the second variable magnification optical system, the size of the illumination region formed in the illumination target surface can be changed and adjusted to a desired value. Also, by changing the focal length of the first variable magnification optical system, the illumination NA, which has changed with the change in the focal length of the second variable magnification optical system, can be adjusted to a desired value.

[0028] As such, the illumination optical apparatus of the present invention may adjust the illumination NA and the size of the illumination region to a desired value, respectively, while preferably reducing light loss, by adjusting the focal length (or magnification) of each of the first variable magnification optical system and the second variable magnification optical system. Thus, an exposure apparatus incorporating the illumination optical apparatus of the present invention may adjust a size and σ value of an exposure region to a desired value, respectively, while preferably reducing light loss in an aperture stop or an illumination field stop. That is, the exposure apparatus of the present invention may set a size and σ value of an illumination region (exposure region), respectively, to a proper value according to a characteristic of a micro device to be manufactured or a characteristic of a mask to be used; and may perform good projection exposure with a high throughput based on high exposure illuminance and a good exposure condition.

[0029] Further, an exposure method or a manufacturing method of a micro device, which exposes a pattern of a mask disposed in the illumination target surface to a photosensitive substrate using the illumination optical apparatus of the present invention, may manufacture a good micro device, since it may perform a good projection exposure based on a good

exposure condition.

[0030] Further, in the present invention, if a light intensity distribution in a pupil position of an illumination optical system (a position of a secondary light source formed by an optical integrator or a position optically conjugated therewith) or in the vicinity thereof is changed by a changing means or a light converting means (e.g., a mechanism for positioning one of a diffraction optical member 3 for forming a circular light, a diffraction optical member 3a for forming an annular light, and a diffraction optical member 3b for forming a quadrupolar light in an illumination optical path), in order to change an exposure condition or an illumination condition, the illumination numerical aperture is changed. However, adjustment (change) of a magnification or a focal length of the first variable magnification optical system as an adjustment means can correct the change in the illumination numerical aperture. Accordingly, an exposure apparatus and a method for manufacturing a micro device, which may expose a mask pattern to a photosensitive substrate such as a wafer based on the desired exposure condition or illumination condition, can be realized.

[0031] The embodiments of the present invention will now be described with reference to the accompanying drawings. Fig. 1 schematically shows a configuration of an exposure apparatus having an illumination optical apparatus according to the first embodiment of the present invention. Further, in Fig. 1, the illumination optical apparatus is configured to perform a typical circular illumination. The exposure apparatus in Fig. 1 has an excimer laser light source, for example which supplies light having such a wavelength of 248nm or 193nm as a light source 1 for supplying an exposure light (illumination light). The substantially parallel light, which is emitted from the light source 1 along a standard optical axis AX, passes through a shaping optical system (not shown) to be shaped to light with a predetermined rectangular cross-section and then enters into a light delay part 2.

[0032] Fig. 2 is a perspective view illustrating an internal configuration and operation of the light delay part 2. As shown in Fig. 2, the light delay part 2 is provided with a half mirror 200 obliquely disposed at 45 degrees with respect to the optical axis AX. Thus, the light, which enters into the half mirror 200 along the optical axis AX, is divided into the light passing through the half mirror 200 and the light reflected in a +X direction from the half mirror 200. The light passing through the half mirror 200 then enters into a diffraction optical element (DOE) 3 for circular illumination.

[0033] Further, the light reflected in the +X direction from the half mirror 200 is reflected in a –Y direction at a first reflection mirror 201, and is further reflected in a –X direction at a second reflection mirror 202, and is then reflected in a +Y direction at a third reflection mirror 203. Hereafter, it is reflected in a +X direction at a fourth reflection mirror 204 and finally returns to the half mirror 200. The light returning to the half mirror 200 is divided into the light passing through the half mirror 200 and the light reflected in a –Z direction at the half mirror 200. The light reflected in the –Z direction at the half mirror 200 enters into the diffraction optical element 3 along the optical axis AX. On the other hand, the light passing through the half mirror 200 passes through the first reflection mirror 201 to the fourth

reflection mirror 204 and then returns to the half mirror 200 again.

[0034] As such, the light that enters into the light delay part 2 is divided into the light passing through the half mirror 200 as a beam splitter and the light reflected at the half mirror 200. The light reflected at the half mirror 200 is sequentially deflected by the four reflection mirrors 201 to 204, which are arranged to form a rectangular delayed optical path, and then returns to the half mirror 200. In this case, the four reflection mirrors 201 to 204 are disposed such that an incident position of the light that enters into the half mirror 200 along the optical axis AX coincides with a re-incident position that the light returns to the half mirror 200 through the rectangular delayed optical path.

[0035] Thus, light P1, which is reflected in the –Z direction at the half mirror 200 after passing through the delayed optical path one time, is emitted along the same optical axis AX as that of light P0 passing through the half mirror 200 without passing through the delayed optical path. As a result, a difference in optical path length equivalent to an optical path length of the delayed optical path is imparted between the light P0 and the light P1. Similarly, light P2, which is reflected at the half mirror 200 after passing through the delayed optical path two times, is emitted along the same optical axis AX as those of the light P0 and the light P1. In this case, a difference in optical path length equivalent to twice of the optical path length of the delayed optical path is imparted between the light P0 and the light P2, while the difference in optical path length equivalent to the optical path length of the delayed optical path is imparted between the light P1 and the light P2. That is, the light delay part 2 divides the light incoming along the optical axis AX into a plurality of light (which are infinite light in theory, however, when ignoring the influences of light with small energy, they are finite light in practical) according to time, and imparts the difference in optical path length equivalent to the optical path length of the delayed optical path between two time-successive light.

[0036] In general, a reflectance of a reflection mirror differs between the P polarization incidence and S polarization incidence, wherein the S polarization incidence may ensure a reflectance higher than the P polarization incidence. Thus, in order to avoid light loss in the delayed optical path, the light delay part 2 is preferably configured such that light enters at the S polarization state with respect to the four reflection mirrors 201 to 204. In this embodiment, since light enters at the P polarization state with respect to the half mirror 200 as shown in Fig. 2, the S polarization incidence can occur at the four reflection mirrors 201 to 204.

[0037] As such, since the light delay part 2 divides the light incoming along the optical axis AX into a plurality of light according to time, the difference in optical path length equivalent to the optical path length of the delayed optical path is imparted between two time-successive light, wherein, the imparted difference in optical path length is set more than a coherent distance in time of light from the coherent light source 1. Thus, the coherence in wavefronts divided by the light delay part 2 can be decreased and occurrence of interference fringes or speckles in the illumination target surface can be preferably reduced. A further detailed

configuration and operation of such a light delaying means are disclosed in the following references: Japanese Patent Application Laid-open No. (Hei) 11-174635, Japanese Patent Application Laid-open No. (Hei) 10-117464, Japanese Patent Application Laid-open No. (Hei) 11-21591, and Japanese Patent Application Laid-open No. (Hei) 11-25629.

[0038] As described above, the substantially parallel light with a rectangular cross section passing through the light delay part 2 enters into the diffraction optical element 3. In general, the diffraction optical element forms steps having a pitch corresponding to a wavelength of an exposure light (illumination light) on a glass substrate and diffracts an incident light to a desired angle. Specifically, the diffraction optical element 3 for circular illumination converts the substantially parallel light with a rectangular cross section incoming along the optical axis AX into divergence light with a circular cross section. As such, the diffraction optical element 3 constitutes a light converting optical system for converting the light from the light source 1 into divergence light with a predetermined cross section (in this embodiment, circular cross section).

[0039] The circular divergence light passing through the diffraction optical element 3 passes through a zoom lens 4 as a first condenser optical system (a first variable magnification optical system) and then enters into a micro fly's eye 5 as a multiple light source forming means or a light integrator. In this way, a circular illumination region is formed in an incident surface of the micro fly's eye 5. Further, a size of the illumination region (e.g., a diameter or radius thereof) varies depending upon a focal length of the zoom lens 4 as described below. Further, the micro fly's eye 5 is an optical element comprising a number of micro lenses (micro lens element) having a positive refraction power, which are densely arranged lengthwise and widthwise. In general, a micro fly's eye is configured by etching a flat glass substrate, thereby forming a micro lens group.

[0040] In this case, each of micro lens constituting a micro fly's eye is finer than each of lens elements constituting a fly' eye lens. Further, the micro fly's eye is different from a fly's eye lens comprising lens elements separated apart from one another and a number of micro lenses are integrally formed without separation from one another. However, the micro fly's eye is equal to the fly's eye lens in that lens elements having a positive refracting power are arranged lengthwise and widthwise. In Fig. 1 and Figs 3, 6 and 7, which are related to Fig. 1, only a small number of the micro lenses constituting the micro fly's eye are illustrated for clarification of the drawing.

[0041] Accordingly, the light which enters into the micro fly's eye 5 is two-dimensionally divided by a number of the micro lenses, thereby forming one light source image, respectively, in a rear focal surface of each of the micro lenses (i.e., in the vicinity of an emitting side thereof). In this way, a number of circular light sources (hereinafter, secondary light source), which are equal to the illumination region formed by the incident light into the micro fly's eye 5, are formed in the rear focal surface of the micro fly's eye 5. As such, the micro fly's eye 5 is a wavefront-splitting type optical integrator and constitutes a multiple light source forming means for forming multiple light sources (multiple lights) based

on the light from the light source 1.

[0042] Further, the zoom lens 4 preferably varies continuously in its focal length, such that a front focal surface of the zoom lens coincides with a diffraction surface of the diffraction optical element 3 and the rear focal surface of the zoom lens coincides with the incident surface of the micro fly's eye 5. Thus, it is preferred that the zoom lens 4 has three lens groups independently movable along the optical axis. The light from the circular secondary light source formed in the rear focal surface of the micro fly's eye enters into an aperture stop 6 for circular illumination, which is disposed in the vicinity thereof. The aperture stop 6 has a circular opening (light transmitting portion) corresponding to the circular secondary light source formed in the rear focal surface of the micro fly's eye 5.

[0043] Further, the diffraction optical element 3 is configured to be freely inserted to and retracted from the illumination optical path. Also, the diffraction optical element 3 is configured to be exchangeable with a diffraction optical element 3a for annular illumination or a diffraction optical element 3b for quadrupolar illumination. The configurations and operations of the diffraction optical element 3a for annular illumination and the diffraction optical element 3b for quadrupolar illumination will be described below. Further, as described above, the zoom lens 4 is configured to successively vary in its focal length within a predetermined range. Further, the aperture stop 6 is configured to be freely inserted to and retracted from the illumination optical path. Also, the aperture stop 6 is configured to be exchangeable with a plurality of aperture stops for circular illumination with differently sized openings, a plurality of aperture stops for annular illumination with differently sized openings, or a plurality of aperture stops for quadrupolar illumination with differently sized openings.

[0044] In this embodiment, a first drive system 22, which is operated in accordance with the commands from a control system 21, performs replacement among the diffraction optical element 3 for circular illumination, the diffraction optical element 3a for annular illumination, and the diffraction optical element 3b for quadrupolar illumination. Further, a second drive system 23, which is operated in accordance with the commands from the control system 21, changes in the focal length of the zoom lens 4.

[0045] Further, a third drive system 24, which is operated in accordance with the commands from the control system 21, performs replacement between the aperture stop 6 and another aperture stop. Further, the replacement between the aperture stop 6 for circular illumination and another aperture stop may be performed in any other appropriate manner, such as a turret manner or a slide manner. Further, instead of an aperture stop of a turret manner or a slide manner, an aperture stop, which is capable of suitably changing a size or shape of a light transmission region, may be fixedly mounted in the illumination optical path. Further, instead of a plurality of circular aperture stop, an iris diaphragm capable of successively changing a diameter of a circular opening may be provided.

[0046] The light from the secondary light source, which passes through the aperture stop 6 having a circular opening, is condensed by a zoom lens 7 (second condenser optical system,

second variable magnification optical system), and then superposedly illuminates a predetermined surface which is optically conjugated with a mask 10 (it will be described below). In this way, a rectangular illumination region similar with the shape of each micro lens constituting the micro fly's eye 5 is formed in the predetermined surface. Further, as described below, an illumination NA and a size of the rectangular illumination region formed in the predetermined surface vary depending upon the focal length of the zoom lens 7.

[0047] Preferably, the zoom lens 7 successively changes its focal length such that a front focal surface of the zoom lens 7 and the rear focal surface of the micro fly's eye 5 coincide with each other and the rear focal plane of the zoom lens 7 and the aforementioned predetermined surface coincide with each other. Accordingly, it is preferred that the zoom lens 7 is provided with three lens groups independently movable along the optical axis as the zoom lens 4. As such, the zoom lens 7 is configured to successively change its focal length within a predetermined range, wherein the change in focal length is performed by a fourth drive system 25 that is operated in accordance with the commands from the control system 21.

[0048] Mask blinds 8 are disposed as illumination field stops in the predetermined surface, which are optically conjugated with the mask 10. The light passing through an opening (light transmitting portion) of the mask blinds 8 is condensed by a relay optical system 9, and then uniformly and superposedly illuminates the mask 10 with predetermined pattern formed thereon. In this way, the relay optical system 9 forms an image of the rectangular opening of the mask blinds 8 on the mask 10.

[0049] The light transmitting the patterns of the mask 10 passes through the projection optical system 11 and then forms an image of the mask pattern on a wafer (or plate) 12 of a photosensitive substrate. Further, the wafer 12 is held on a wafer stage 13 which is two-dimensionally movable within a plane orthogonal to the optical axis AX of the projection optical system 11. In this way, the patterns of the mask 10 are exposed on each exposure region (shot region) of the wafer 12 one after another by performing an one-shot exposure or a scan exposure (scanning exposure) while controlling the two-dimensional driving of the wafer 12.

[0050] In the one-shot exposure method, the mask patterns are exposed at a time on each exposure region of a wafer according to what is called a step-and-repeat method. In this case, the shape of an illumination region on the mask 10 becomes a rectangular shape similar to a square, and a cross-section of each micro lens of the micro fly's eye 5 also becomes a rectangular shape similar to a square. Meanwhile, in the scan exposure method, the mask patterns are scan-exposed on each exposure region of the wafer, while the mask and the wafer are moved with respect to a projection optical system, according to what is called a step and scan method. In this case, the shape of an illumination region on the mask 10 becomes a rectangular shape such that a ratio of a shorter side to a longer side is 1:3, and a cross-section of each micro lens of the micro fly's eye 5 becomes a rectangular shape similar to the aforementioned rectangular shape.

[0051] Fig. 3 illustrates relationship between the focal length of the zoom lens 4 and the zoom lens 7; and the illumination NA and the size of the rectangular illumination region formed in the predetermined surface conjugated with the mask 10. In Fig. 3(a), the light 30 emitted from an intersection between the diffracting surface of the diffraction optical element 3 and the optical axis AX at a maximum emitting angle θ1 passes through the zoom lens 4 set to a maximum focal length f11 to be parallel to the optical axis AX, and then enters into the micro fly's eye 5. The micro fly's eye 5 consists of the micro lenses with a focal length fm. In Fig. 3, the size of each micro lens is d.

[0052] An outermost light 31 emitted parallel to the optical axis AX from the micro fly's eye 5 passes through the zoom lens 7 set to a maximum focal length f21, and then arrives at the intersection between the optical axis AX and the predetermined surface 32 conjugated with the mask 10 at an incidence angle θ21. In this way, the rectangular illumination region 33 similar with the shape of the micro lens is formed in the predetermined surface 32. Further, in Fig. 3, the size of the illumination region 33 is ø1.

[0053] In such a case, as shown in Fig. 3(b), while changing the focal length of the zoom lens 4 from the maximum focal length f11 to the minimum focal length f12, the focal length of the zoom lens 7 is changed from the maximum focal length f21 to the minimum focal length f22. In this case, the light 30 emitted from the intersection between the optical axis AX and the diffracting surface of the diffraction optical element 3 at the maximum emitting angle θ1 passes through the zoom lens 4 set to the minimum focal length f12 to be parallel to the optical axis AX, and then enters into the micro fly's eye 5.

[0054] The outermost light 31 emitted parallel to the optical axis AX from the micro fly's eye 5 passes through the zoom lens 7 set to the minimum focal length f22, and then arrives at the intersection between the optical axis AX and the predetermined surface 32 conjugated with the mask 10 at an incidence angle θ22. In this way, the rectangular illumination region 33 similar with the shape of the micro lens is formed in the predetermined surface 32. In Fig. 3, the size of the illumination region 33 is ø2.

[0055] In Fig. 3(a), the following formulas (1) and (2) are satisfied:

$$f11 \cdot \sin\theta12 = f21 \cdot \sin\theta21 \qquad (1)$$

$$ø1 = (f21 / fm)\, d \qquad (2)$$

Further, in Fig. 3(b), the following formulas (3) and (4) are satisfied:

$$f12 \cdot \sin\theta1 = f22 \cdot \sin\theta22 \qquad (3)$$

$$ø2 = (f22 / fm)\, d \qquad (4)$$

[0056] Referring to the formulas (2) and (4) as above, it should be noted that the

illumination region 33 is a projection of the micro lens by the zoom lens 7 and the size ø of the illumination region 33 is proportional to the focal length f2 of the zoom lens 7. That is, it may readily be shown that the size ø1 of the illumination region 33 in Fig. 3(a) is the maximum size and the size ø 2 of the illumination region 33 in Fig. 3(b) is the minimum size.

[0057] Referring to the formulas (1) and (3) as above, since θ1 is a characteristic value of the diffraction optical element 3, it should be noted that a sine value (sinθ) of the incidence angle θ2 into the predetermined surface 32 depends upon a ratio of the focal length f1 of the zoom lens 4 to the focal length f2 of the zoom lens 7(i.e., f1/f2). In other words, it may readily be shown that the illumination NA of the illumination region 33 in Fig. 3(a) is proportional to f11/f21 and the illumination NA of the illumination region 33 in Fig. 3(b) is proportional to f12/f22.

[0058] Further, as shown in Figs. 3(a) and 3(b), the size of the circular illumination region formed in the incident surface of the micro fly's eye 5 is proportional to the focal length f1 of the zoom lens 4. That is, it should be noted that the size of the illumination region formed in the incident surface of the micro fly's eye 5 in Fig. 3(a) is maximum and the size of the illumination region formed in the incident surface of the micro fly's eye 5 in Fig. 3(b) is minimum.

[0059] As such, if the focal length f2 of the zoom lens 7 is changed, the size of the illumination region formed in the predetermined surface 32, the size of the illumination region formed in the pattern surface of the mask 10, and the size of the exposure region formed in the exposure surface of the wafer 12 are changed. Further, with change in the focal length f2 of the zoom lens 7, the illumination NA in the predetermined surface 32 and further the illumination NA in the pattern surface of the mask 10 are changed. More specifically, if the focal length f2 of the zoom lens 7 is enlarged, the illumination region on the mask 10 is enlarged and thus the illumination NA is enlarged. As such, the zoom lens 7 constitutes the second variable magnification optical system for changing the size of the illumination region formed on the mask 10 (and further the wafer 12) that is an illumination target surface.

[0060] Meanwhile, if the focal length f1 of the zoom lens 4 is changed, the size of the illumination region formed in the incident surface of the micro fly's eye 5 is changed without change of the size of the illumination region formed in the pattern surface of the mask 10, thereby changing the illumination NA on the mask 10. More specifically, if the focal length f1 of the zoom lens 4 is small, only the illumination NA on the mask 10 becomes small without any change in the size of the illumination region on the mask 10. As such, the zoom lens 4 constitutes the first variable magnification optical system for changing only the illumination NA on the mask 10 that is the illumination target surface.

[0061] Accordingly, in this embodiment, the illumination region of a desired size can be obtained on the mask 10 without any substantial light loss in the mask blinds 8 by setting the focal length of the zoom lens 7 to a predetermined value. Further, the illumination NA of a

desired size can be obtained on the mask 10 without any substantial light loss in the aperture stop 6 by setting the focal length of the zoom lens 4 to a predetermined value with respect to the focal length of the zoom lens 7 set to the predetermined value.

[0062] As described above, the diffraction optical element 3 is configured to be inserted to and retracted from the illumination optical path. Further, the diffraction optical element 3 is configured to be exchangeable with the diffraction optical element 3a for annular illumination and the diffraction optical element 3b for quadrupolar illumination.
The annular illumination obtained by providing the diffraction optical element 3a, instead of the diffraction optical element 3a, in the illumination optical path will be described below.

[0063] Fig. 4 illustrates an operation of the diffraction optical element 3a for annular illumination. As shown in Fig. 4, the diffraction optical element 3a for annular illumination converts the circular light, which has a circular cross section and normally enters along the optical axis AX, into a ring-shaped light having a ring-shaped cross section by omnidirectionally and equiangularly diffracting the light with respect to the optical axis AX. Thus, when the parallel light of a circular cross section enters into the diffraction optical element 3a along the optical axis AX, it becomes an annular divergence light as shown in Fig. 4. As such, the diffraction optical element 3a constitutes the light converting optical system for converting the light from the light source 1 into substantially annular divergence light.

[0064] The annular divergence light passing through the diffraction optical element 3a passes through the zoom lens 4 and then enters into the micro fly's eye 5. In this way, an annular illumination region is formed in the incident surface of the micro fly's eye 5. As a result, an annular secondary light source having the same shape with the illumination region formed in the incident surface is formed in the rear focal surface of the micro fly's eye 5. As such, the annular secondary light source is formed in the rear focal surface of the micro fly's eye 5 without any light loss based on the light from the light source 1.

[0065] The circular aperture stop is changed with the annular aperture stop, corresponding to the change from the diffraction optical element 3 to the diffraction optical element 3a. In this case, the annular aperture stop positioned in the illumination optical path is an aperture stop with an annular opening corresponding to the annular secondary light source. As such, by using the diffraction optical element 3a for annular illumination, the annular secondary light source can be formed without any light loss based on the light from the light source 1. As a result, the annular illumination can be performed while reducing light loss in the aperture stop restricting the light from a secondary light source.

[0066] Subsequently, the quadrupolar illumination, for example, obtained by providing the diffraction optical element 3b in the illumination optical path instead of the diffraction optical element 3, will be described below. Fig. 5 illustrates an operation of the diffraction optical element 3b for quadrupolar illumination. As shown in Fig. 5, the diffraction optical element 3b for quadrupolar illumination converts the circular light, which has a circular cross section and normally enters along the optical axis AX, into four narrow lights by equiangularly

diffracting it relative to the optical axis AX in four specific directions. Thus, when the parallel light of a circular cross section enters into the diffraction optical element 3b along the optical axis AX, the light becomes quadrupolar divergence light as shown in Fig. 5. As such, the diffraction optical element 3b constitutes the light converting optical system for converting the light from the light source 1 into the four divergence light that is offset relative to the optical axis AX.

[0067] The quadrupolar divergence light passing through the diffraction optical element 3b passes through the zoom lens 4 and then enters into the micro fly's eye 5. In this way, a quadrupolar illumination region is formed in the incident surface of the micro fly's eye 5. As a result, a quadrupolar secondary light source having the same shape with the illumination region formed in the incident surface is formed in the rear focal surface of the micro fly's eye 5. As such, the quadrupolar secondary light source is formed in the rear focal surface of the micro fly's eye 5 with almost no light loss based on the light from the light source 1.

[0068] The circular aperture stop is changed with the quadrupolar aperture stop corresponding to the change from the diffraction optical element 3 to the diffraction optical element 3b. In this case, the quadrupolar aperture stop positioned in the illumination optical path is an aperture stop with four openings corresponding to the quadrupolar secondary light source. As such, by using the diffraction optical element 3b for quadrupolar illumination, the quadrupolar secondary light source can be formed without any light loss based on the light from the light source 1. As a result, the quadruple illumination can be performed while reducing light loss in the aperture stop restricting the light from a secondary light source.

[0069] Hereinafter, an adjustment process of the illumination NA and the size of the illumination region will be described in detail. First, information on various masks to be exposed one by one according to a step-and-repeat method or a step-and-scan method, and information on the illumination condition of various masks or the exposure condition of a wafer to be exposed one by one, etc. are inputted into the control system 21 via the input means 20, such as a keyboard. The control system 21 stores information on various masks or wafers, such as a desired size of an illumination region (exposure region), an optimal illumination NA, an optimal line width (resolution), a desired depth of focus, etc., in an internal memory part, thereby supplying a suitable control signal to the first drive system 22 to the fourth drive system 25 in response to the input from the input means 20.

[0070] That is, in case of performing a typical circular illumination based on an illumination region of a desired size, an optimal illumination NA, an optimal resolution, and a desired depth of focus, the first drive system 22 positions the diffraction optical element 3 for circular illumination in the illumination optical path in accordance with the commands from the control system 21. Also, in order to obtain an illumination region having a desired size on the mask 10, the fourth drive system 25 sets up the focal length of the zoom lens 7 in accordance with the commands from the control system 21. Further, in order to obtain a desired illumination NA on the mask 10, the second drive system 23 sets up the focal length of the zoom lens 4 in accordance with the commands from the control system 21. Further,

in order to restrict the circular secondary light source formed in the rear focal surface of the micro fly's eye 5 to a state where light loss is preferably suppressed, the third drive system 24 positions a desired circular aperture stop in the illumination optical path in accordance with the commands from the control system 21.

[0071] Further, if necessary, the illumination NA and the size of the illumination region formed on the mask 10 may be suitably changed independently from each other by changing the focal length of the zoom lens 4 by the second drive system 23 or changing the focal length of the zoom lens 7 by the fourth drive system 25. In this case, according to the change in the size of the circular secondary light source depending upon change in the focal length of the zoom lens 4, a desired circular aperture stop is selected and positioned in the illumination optical path.

[0072] As described above, the input means 20, the control system 21, the second drive system 23 and the third drive system 24 constitute the adjusting system for adjusting each focal length of the first variable magnification optical system and the second variable magnification optical system in order to set the illumination NA and the size of an illumination region to a desired value. In this way, the optimized circular illumination can be accomplished by setting the illumination NA and the size of an illumination region on the mask 10 to a desired value, respectively, without any light loss.

[0073] Also, when the annular illumination is performed based on the illumination region with a desired size, optimized illumination NA, optimized resolution, and desired depth of focus, the first drive system 22 positions the diffractive optical element 3a for annular illumination in the illumination optical path in accordance with the commands from the control system 21. Further, in order to obtain the illumination region with a desired size on the mask 10, the fourth drive system 25 sets the focal length of the zoom lens 7 in accordance with the commands from the control system 21. Also, in order to obtain a desired illumination NA on the mask 10, the second drive system 23 sets the focal length of the zoom lens 4 in accordance with the commands from the control system 21. In general, in order to limit the annular secondary light source formed in the rear focal surface of the micro fly's eye lens 5 to the state of reducing preferably light loss, the third drive system 24 positions a desired annular aperture stop in the illumination optical path in accordance with the commands from the control system 21.

[0074] Also, if necessary, by changing the focal length of the zoom lens 4 by the second drive system 23 or changing the focal length of the zoom lens 7 by the fourth drive system 25, the illumination NA and the size of the illumination region formed on the mask 10 can be changed appropriately and independently from each other. In this case, according to the change of the size of the annular secondary light source (i.e., the size circle circumscribed with the annular secondary light source) depending on the change of the focal length of the zoom lens 4, a desired annular aperture stop is selected and positioned in the optical path for illumination. In this way, the optimized annular illumination can be accomplished by setting the illumination NA and the size of an illumination region on the mask 10 to a desired

level without any light loss.

[0075] Also, when the quadrupolar illumination is performed based on the illumination region with a desired size, optimized illumination NA, optimized resolution, and desired depth of focus, the first drive system 22 positions the diffractive optical element 3b for annular illumination in the illumination optical path in accordance with the commands from the control system 21. Further, in order to obtain the illumination region with a desired size on the mask 10, the fourth drive system 25 sets the focal length of the zoom lens 7 in accordance with the commands from the control system 21. Also, in order to obtain a desired illumination NA on the mask 10, the second drive system 23 sets the focal length of the zoom lens 4 in accordance with the commands from the control system 21. Also, in order to limit the quadrupolar secondary light source formed in the rear focal surface of the micro fly's eye lens 5 to the state of reducing adequately light loss, the third drive system 24 positions a desired quadrupolar opening aperture in the illumination optical path in accordance with the commands from the control system 21.

[0076] Also, if necessary, by changing the focal length of the zoom lens 4 by the second drive system 23 or changing the focal length of the zoom lens 7 by the fourth drive system 25, the illumination NA and the size of the illumination region formed on the mask 10 can be changed appropriately and independently from each other. In this case, according to the change of the size of the quadrupolar secondary light source (i.e., the size of circle circumscribed with the quadrupolar secondary light source) depending on the change of the focal length of the zoom lens 4, a desired quadrupolar aperture stop is selected and positioned in the illumination optical path. In this way, the optimized quadrupolar illumination can be accomplished by setting the illumination NA and the size of an illumination region on the mask 10 to a desired level without any light loss.

[0077] As described above, in the present embodiment, by controlling the focal length of the zoom lens 4 as a first variable magnification optical system and the focal length of the zoom lens 7 as a second variable magnification optical system, the illumination and the size of an illuminated region on the mask 10 and illumination NA, and the size of the light exposure region on the wafer 12 and σ value can be adjusted to a desired level, while light loss in the aperture stop 6 or the illumination field stop 8 is reduced adequately. That is, the exposure device of the present embodiment enables the projection exposure with higher throughput based on the high exposure illuminance and desired exposure condition by setting the size of the illumination region (exposure region) and σ value to an optimal value depending on the characteristic of the micro device or the characteristic of the mask 10.

[0078] Also, in the above-described embodiment, the modification illumination, such as annular illumination or quadrupolar illumination, and conventional circular illumination can be accomplished, while the light loss in the aperture stop for limiting the secondary light source is reduced adequately. Therefore, the resolution and the depth of focus of the projection optical system suitable for a micro pattern to be projection-exposed by illumination can be achieved by changing the type of modification illumination appropriately.

As a result, a preferable projection exposure with higher throughput can be accomplished based on the high exposure illuminance and preferable exposure condition.

[0079] Also, in order to change the exposure condition or illumination condition, if a distribution of light intensity in a pupil position of the illumination optical system (the position of the secondary light source formed by the light integrator or optically conjugate position) or an adjacent position thereof is changed by a modification means or light converting means (for example, a device for setting one of the diffraction optical member 3 for forming the circular light, the diffraction optical member 3a for forming the annular light, and the diffraction optical member 3b for forming the quadrupolar light) in the illumination optical path, the illumination numerical aperture NA may be changed. The change of the illumination numerical aperture according to the change in an exposure condition or illumination condition can be compensated by adjusting (changing) the magnification of the first variable magnification optical system 4 or the focal length.

[0080] In this case, the control system 21 outputs appropriate control signals into the first drive system 22, the second drive system 23, and the third drive system 24, respectively, based on the exposure condition or illumination condition of each mask or each wafer memorized in an interior memory part through the input means 20. That is, an appropriate diffraction optical element 3, 3a, 3b is set on the illumination optical path by the first drive system 22, an aperture stop with appropriate shape or appropriate size is set on the illumination optical path by the third drive system 24, and the first variable magnification optical system is adjusted (changed) to appropriate magnification or focal length for compensating the change of the illumination numerical aperture. Thereby, the exposure device and the method for producing a micro device, which can expose a preferable mask pattern to a photosensitive substrate, such as a wafer, based on the desired exposure condition or desired illumination, can be realized.

[0081] Fig. 6 is an approximate view of an exposure device with an illumination optical apparatus according to the second embodiment. The second embodiment has similar configuration with the first embodiment. However, the second embodiment is different with the first embodiment in that the first embodiment uses a light integrator as a multiple light source forming means, which has an invariable focal length and is comprised of one micro fly's eye lens, and the zoom lens 7 with a variable focal length as a condenser optical system, whereas the second embodiment uses the micro fly's eye lenses group 50 as a multiple light source forming means, which has a variable focal length and is comprised of three micro fly's eye lenses 51~53, and condenser lens 70 with an invariable focal length as a condenser optical system.

[0082] As shown in the Fig. 6, the element whose function is similar with the element of the first embodiment is referred to with the same numerical reference. Hereafter, the second embodiment will be described focusing on the difference with the first embodiment. Also, in the Fig. 6, the illumination optical apparatus is set for conventional circular illumination; however, it is also possible to implement an annular illumination or quadrupolar illumination

by changing a diffraction optical element, as same as the first embodiment. The detail explanation for such possibility will be omitted.

[0083] The second embodiment has a micro fly's eyes group 50 that comprises a first micro fly's eye 51 consisting of a micro lens with positive refractive power; a second micro fly's eye 52 consisting of a micro lens with negative refractive power; and a third micro fly's eye 51 consisting of a micro lens with positive refractive power, wherein the micro fly's eyes are arranged in order from the light source side. The micro lenses, which constitute the micro fly's eyes 51~53, have a cross section of rectangular shape and the sizes thereof are the same.

[0084] Also, the first micro fly's eye 51 and the second micro fly's eye 52 are movable independently along the optical axis AX, and the third micro fly's eye 53 is fixed along the optical axis AX. In order to prevent a rear focus surface of the micro fly's eyes group 50 from moving, the first micro fly's eye 51 and the second micro fly's eye 52 move independently along the optical axis AX, and thereby, the focal length of the micro fly's eyes group 50 is allowable to be changed continuously from the maximum focal length f501 to the minimum focal length f502. Also, the focal length of the micro fly's eyes group 50 is changed by the drive system that is driven in accordance with the commands from the control system, as same as the first embodiment.

[0085] Fig. 7 illustrates a relationship between the focal lengths of the zoom lens 4 and the micro fly's eyes group 50; and the illumination NA and the size of the rectangular illumination region formed in a predetermined surface conjugated with the mask 10. In Fig. 7(a), the light 30 emitted from an intersection between the optical axis AX and the diffraction surface of the diffractive optical element 3 as the maximum emitting angle θ1 becomes to be parallel with the optical axis AX through the zoom lens 4 set to the maximum focal length f11, and then enters into the micro fly's eyes group 50. The micro fly's eyes group 50 is set to the maximum focal length f501. In Fig. 7, the size of each micro lens of the micro fly's eyes 51~53, which constitute the micro fly's eyes group 50, is d.

[0086] The outmost light 31 emitted from the micro fly's eyes group 50 parallel with the optical axis AX passes through the condenser lens 70 with a focal length f70, and then arrives at the intersection between the optical axis AX and the predetermined surface 32 conjugated with the mask 10 as an incidence angle θ21. Thereby, an illumination region 33 of rectangular shape, which is similar with the shape of micro lens, is formed in the predetermined surface 32. Further, the size of the illumination region 33 in Fig. 7 is ø3.

[0087] As shown in Fig. 7(b), the focal length of the zoom lens 4 is changed from the maximum focal length f11 to the minimum focal length f12, while the focal length of the micro fly's eyes group 50 is changed from the maximum focal length f501 to the minimum focal length f502. In this case, the light 30 emitted as an emitting angle θ1 from the intersection between the optical axis AX and the diffraction surface of the diffraction optical element 3 becomes to be parallel with the optical axis AX through the zoom lens 4 set to the minimum focal length f12, and then enters into the micro fly's eyes group 50 set to the

minimum focal length f502.

[0088] The outmost light 30 emitted parallel with the optical axis AX from the micro fly's eyes group 50 passes through the condenser lens 70 with a focal length f70, and then arrives at the intersection between the optical axis AX and the predetermined surface 32 conjugated with the mask 10 as an incidence angle θ22. Thereby, an illumination region 33 of rectangular shape, which is similar with the shape of micro lens, is formed in the predetermined surface 32. Further, the size of the illumination region 33 in Fig. 7 is ø4.

[0089] In Fig. 7(a), the following formulas (5) and (6) are satisfied:

$$f11 \cdot \sin\theta 1 = f70 \cdot \sin\theta 21 \qquad (5)$$

$$\text{ø}3 = (f70 / f501)\, d \qquad (6)$$

Also, in Fig. 7(b), the following formulas (7) and (8) are satisfied:

$$f12 \cdot \sin\theta 1 = f70 \cdot \sin\theta 22 \qquad (7)$$

$$\text{ø}4 = (f70 / f502)\, d \qquad (8)$$

[0090] Referring to the formulas (6) and (8) as above, it should be noted that the size ø of the illumination region 33 is inversely proportional to the micro fly's eyes group 50. That is, it may readily be shown that the size ø3 of the illumination region 33 in Fig. 7(a) is the minimum size, and the size ø4 of the illumination region 33 in Fig. 7(b) is the maximum size. Further, referring to the formulas (5) and (7) as above, since the values of θ1 and f70 are invariable, it should be noted that a sine value (sin θ2) of the incidence angle θ2 into the predetermined surface 32 depends on the focal length f1 of the zoom lens 4. That is, it may readily be shown that the illumination NA of the illumination region 33 in Fig. 7(a) is maximum and is proportional to f11, and the illumination NA of the illumination region 33 in Fig. 7(b) is minimum and is proportional to f12.

[0091] As described above, if the focal length f 50 of the micro fly's eyes group 50 is changed, the illumination region formed in the predetermined surface 32 and the size of the illumination region formed in the pattern surface of the mask 10 are changed. More specifically, if the focal length f50 of the micro fly's eyes group 50 is enlarged, only the size of the illumination region on the mask 10 is to be smaller without the change of the illumination NA on the mask 10. As such, the micro fly's eyes group 50 constitutes the multiple light source forming means; and a part of the second variable magnification optical system for changing the size of the illumination region formed on the mask 10 (further, on the wafer 12), which is an illumination target surface.

[0092] In the meantime, if the focal length f1 of the zoom lens 4 is changed, the size of the illumination region formed in the incident surface of the micro fly's eyes group 50 is changed,

and thereby, the illumination NA on the mask 10 is changed. More specifically, if the focal length f1 of the zoom lens 4 is smaller, only the illumination NA on the mask 10 becomes to be smaller without changing the size of the illumination region on the mask 10. As such, the zoom lens 4 constitutes a part of the first variable magnification optical system for changing the illumination NA only.

[0093] Thus, in the second embodiment, by setting the focal length of the micro fly's eyes group 50 to a predetermined value, the illumination region with a desired size on the mask 10 can be achieved without substantial light loss in the mask blind 8.

[0094] Fig. 8 schematically shows a configuration of an exposure device with an illumination optical apparatus according to the third embodiment. The third embodiment has similar configurations with the first embodiment. However, the third embodiment is basically different with the first embodiment in that the embodiment 1 uses a micro fly's eye lens, i.e., a wavefront-splitting type optical integrator, as a multiple light source forming means, whereas the third embodiment uses the rod type integrator 500, i.e., an inner surface reflection type optical integrator.

[0095] Therefore, as shown in the Fig. 8, the element whose function is similar with the element of the first embodiment is referred to with the same numerical reference. Hereafter, the third embodiment will be described focusing on the difference with the first embodiment. Further, in the Fig. 8, the illumination optical apparatus is set for conventional circular illumination; however, it is also possible to implement an annular illumination or quadrupolar illumination by changing a diffraction optical element, as same as the first embodiment. The detail explanation for such possibility will be omitted.

[0096] In the third embodiment, the zoom lens 41 as a first imaging optic system (a first variable magnification optic system), which corresponds to using the rod type integrator 500 instead of the micro fly's eye 5, is installed in the optical path between the diffractive optic element 3 and the rod type integrator 500, and a zoom lens 71 as a second imaging optic system (a second variable magnification optic system) is installed instead of the zoom lens 7 and the relay optic system 9. Also, the mask blind 8 as the illumination field stop is located in adjacent to the emitting surface of the rod type integrator 500.

[0097] In the present invention, the zoom lens 41 is configured to continuously change its imaging magnification m1, while maintaining a diffraction surface of the diffraction optical element 3 and an incident surface of the rod type integrator 500 as an optically conjugated state. Further, the zoom lens 71 is configured to continuously change its imaging magnification m2 while maintaining an emitting surface of the rod type integrator 500 and a pattern surface of the mask 10 as an optically conjugated state. In addition, the change of the magnification of the zoom lens 41 and the zoom lens 71 is performed in accordance with the commands from the control system as the first embodiment.

[0098] The rod type integrator 500 is a glass rod of an internal reflection type which is made

of glass materials such as quartz glass or fluorite, and forms an image of light source according to the number of internal reflection along a surface parallel to the rod incident surface through a condensing point by using total reflection in a boundary surface between the inner and outer portions, i.e., internal total reflection. Most of the images of the light source formed are virtual images, but only the image of the light source in the center (condensing point) is a real image. That is, the light, which enters into the rod type integrator 500, is divided to angle direction by internal reflection, which forms a secondary light source comprising a number of light source images along a surface parallel to the incident surface through the condensing point.

[0099] The light from the secondary light source formed in the incident side by the rod type integrator 500 is superposed in the emitting surface, and then uniformly illuminates on the mask 10, where a predetermined pattern is formed thereon through the zoom lens 71. As described above, the zoom lens 71 optically connects the emitting surface of the rod type integrator 500 and the mask 10 (further, the wafer 12) in the state of almost optically conjugated. Thus, an illumination region of rectangular shape, which is similar with the shape of a cross section of the rod type integrator 500, is formed on the mask 10.

[00100] Fig. 9 illustrates the relation among the magnification of the zoom lens 41 and the zoom lens 71; and the size of the rectangular shaped illumination region formed in a predetermined surface conjugated with the mask 10 and the illumination NA. In Fig. 9 (a), the light beam 30 emitted from the intersection between the diffractive surface of the diffractive optical element 3 and the optical axis AX at an maximum angle θ1 passes through the zoom lens 41 being set with the maximum magnification m11, and then enters into the intersection between the optical axis AX and the incident surface of the rod type integrator 500 with an incident angle θ11. In this configuration, the size of the emitting surface of the rod type integrator 500 in Fig. 9 is d5.

[00101] The light beam 31 emitted from the intersection between the optical axis AX and the emitting surface of the rod type integrator 500 passes through the zoom lens 71 being set with the maximum magnification m21, and then reaches the intersection between the predetermined surface 32 conjugated with the mask 10 and the optical axis AX at the incident angle θ21. By this way, the rectangular shaped illumination region 33, which has a similar shape with the emitting surface of the rod type integrator 500 (in particular, a similar shape with that of the aperture of the mask blind 8), is formed on the predetermined surface 32,. Further, the size of the illumination region 33 in Fig. 9 is ø5.

[00102] As shown in the Fig. 9 (b), the magnification of the zoom lens 41 changes from the maximum magnification m11 to the minimum magnification m12, and simultaneously, the magnification of the zoom lens 71 changes from the maximum magnification m21 to the minimum magnification m22. In this case, the light beam 30 emitted from the intersection between the diffractive surface of the diffractive optical element 3 and the optical axis AX at the maximum emitting angle θ1 passes through the zoom lens 41 being set with the minimum magnification m12, and then enters into the intersection between the optical axis AX and the

incident surface of the rod type integrator 500 at an angle θ12.

[00103] The light beam 31 emitted from the intersection between the optical axis AX and the emitting surface of the integrator 500 with an angle θ12 passes through the zoom lens 71 being set with the minimum magnification m22, and then reaches the intersection between the predetermined surface 32 conjugated with the mask 10 and the optical axis AX with the incident angle θ22. By this way, the rectangular shaped illumination region 33, which is similar to the shape of the emitting surface of the rod type integrator 500, is formed on the predetermined surface 32. The size of the illumination region 33 in Fig. 9 is ø6.

[00104] With respect to Fig. 9 (a), the following equations 9 and 10 are given:

$$\theta 11 = m11 \cdot \theta 1 = m21 \cdot \theta 2 \qquad (9)$$

$$ø5 = m21 \cdot d5 \qquad (10)$$

Further, with respect to Fig. 9 (b), the following equations 11 and 12 are given:

$$\theta 12 = m12 \cdot \theta 1 = m22 \cdot \theta 2 \qquad (11)$$

$$ø6 = m22 \cdot d5 \qquad (12)$$

[00105] With reference to the equations 10 and 12 as above, it can be understood that the size ø of the illumination region 33 is proportional to the magnification m2 of the zoom lens 71. Accordingly, it can be understood that the size ø5 of the illumination region 33 is maximum in Fig. 9 (a) and the size ø6 of the illumination region 33 is minimum in Fig. 9 (b).

[00106] Also, with reference to the equations 9 and 11 as above, it can be understood that the incident angle θ2 into the predetermined surface 32 depends on the ratio of the magnification m1 of the zoom lens 4 to the magnification m2 of the zoom lens 71, i.e., m1/m2, since the value of θ1 is invariable. In other words, the illumination NA of the illumination region 33 depends on m11/m21 in Fig. 9 (a), and the illumination NA of the illumination region 33 depends on m21/m22 in Fig. 9 (b).

[00107] As described above, if the magnification m2 of the zoom lens 71 is changed, the size of the illumination region formed in the pattern surface of the mask 10 and the illumination NA is changed. More specifically, if the magnification m2 of the zoom lens 71 becomes higher, the illumination region on the mask 10 becomes larger, and thereby, the illumination NA becomes lower. As such, the zoom lens 71 defines the second variable magnification optical system for changing the size of the illumination region formed on the mask which is the illumination target surface.

[00108] Meanwhile, if the magnification m1 of the zoom lens 41 is changed, the size of the illumination region formed on the incident surface of the micro fly's eye 5 is changed, and thereby, the illumination NA on the mask 10 is changed. More specifically, if the magnification m1 of the zoom lens 41 becomes higher, only the illumination NA on the mask 10 becomes higher without any change in the size of the illumination region formed on the pattern surface of the mask 10. As such, the zoom lens 41 defines the first variable magnification optical system for changing only the illumination NA on the mask 10, which is the illumination target surface.

[00109] In this embodiment, therefore, by setting the magnification of the zoom lens 71 to a predetermined value, without substantial light loss in the mask blind 8, the desired size of the illumination region on the mask 10 may be obtained. Further, by setting the magnification of the zoom lens 41 to a predetermined value with regard to the magnification of the zoom lens 7 set to a predetermined value, the desired illumination NA may be obtained.

[00110] Also, in the third embodiment as shown in Fig. 8, as described in the first embodiment as shown in Fig. 1, if the distribution of light intensity in the pupil position of the illumination optical system (the position of the secondary light source formed by the optical integrator or the position optically conjugated with it) or the adjacent position thereof is changed by a modification means or means for changing light (for example, device for setting one of the diffraction optical member (3) for forming circular light, the diffraction optical member (3a) for forming annular light, and the diffraction optical member (3b) for forming quadrupole light in the optical path of illumination) in order to change exposure condition or illumination condition, the illumination numerical aperture NA may be changed. The change of the illumination numerical aperture according to the change of the exposure condition or the illumination condition may be amended by adjusting (changing) the magnification or the focal length of the first variable magnification optical system 41 as an adjusting means or the focal length.

[00111] As described above, in the embodiments shown in Fig. 1 and Fig. 8, the illumination numerical aperture may remain approximately constant by amending the change of the illumination numerical aperture according to the change of the illumination field by the second variable magnification optical system 7 and 71. Such amendment may be made by adjusting (changing) the magnification of the first variable magnification optical system 4 and 41 and the focal length. Therefore, the projection exposure may also be achieved with a high efficiency of illumination under such specific condition.

[00112] However, the distribution of the light intensity on the mask or the wafer is changed by the modification means or the means for changing light (for example, a device for setting one of the diffraction optical member (3) for forming circular light, the diffraction optical member (3a) for forming annular light, and the diffraction optical member (3b) for forming quadrupole light in the optical path of illumination), and thus, the light intensity may not be uniform. In this case, the distribution of the light intensity on the mask or the wafer may become uniform by moving some optical elements (e.g., lens etc.) of the relay optical system

(imaging optical system 9) or the second condenser optical system (variable magnification optical system 7 and 70), or by placing plural replaceable filters having desired angle characteristic for adjusting the distribution of the light intensity in the optical path between the optical integrator 5, 50 and 500 and the mask 10. However, since the illumination numerical aperture may be changed according to said amendment of the light intensity, the change of the illumination numerical aperture according to the amendment of the light intensity by the light intensity amendment means may be amended by adjusting (changing) the magnification or the focal length of the first variable magnification optical system (the first condenser optical system 4, the first imaging optical system 41).

[00113] The light modification means (changing means) described in each embodiment above includes the function of modifying selectively to the light with the plural light intensity having different distributions of light intensity from each other based on the light for exposure. In other words, the function of modifying the light for exposure to either the light having the first distribution of light intensity or the light having the second distribution of light intensity that differs from the first one. Thus, the distribution of light intensity may be changed to desired distribution of light intensity in the pupil position of illumination optical system (the position of the secondary light source formed by the optical integrator or the optically conjugated position with it) or the adjacent position thereof. As such, the light modification means (changing means) could change the distribution of light intensity in the pupil position of illumination optical system or the adjacent position thereof may be configured to switch the diffraction optical elements 3, 3a and 3b forming desired emitting light, as well as to replace convex conical refractive surface prism forming annular light (or prism having concave conical refractive surface) and convex pyramid shaped refractive surface prism forming quadrupole light.

[00114] As such, the light modification means (changing means) may modify light into the desired state of emitting light by setting one of the optical members having a selective diffraction or refraction in the optical path of illumination. Also, if the light modification means (changing means) is a configuration combined with replaceable three diffraction optical elements and variable magnification optical systems, a annular ratio of the annular light (ratio of inner diameter to outer diameter in annular light), a size of circular light and a distance from the center of the quadrupole light can vary continuously in the position of the pupil of the illumination optical system or the adjacent position thereof. Likewise, the light modification means (changing means) may be configured to combine said replaceable prism (refraction optical element) with the variable magnification optical system.

[00115] Further, since each optical member and each stage in each example shown in Fig 1 to 9 is connected electrically, mechanically or optically in order to attain said function, the exposure device in accordance with the present invention may be achieved. Now, with reference to the flow chart as shown in Fig. 10, an example of a way of producing semi-conductor device as micro device by forming predetermined circuit pattern on the wafer as a photosensitive substrate while using the exposure device in each example shown in Figs. 1 to 9 will be described.

[00116] Firstly, metal layer is deposited on one lot of wafers in the step 301 as shown in Fig. 10. In the next step 302, a photo resistance is applied on the lot of wafers. Then, in the step 303, the pattern on the mask (reticle) is exposed and sequentially transferred to each shot region of the lot of wafers through one of the projection optical systems (projection optical units) shown in Figs. 1 to Fig. 9. Then, development of the photo resistance on the lot of wafers is processed in the step 304, and then a circuit pattern corresponding to the pattern on the mask is formed on the shot region of each wafer, i.e., an etching resist pattern. Next, by forming a circuit pattern on a layer thereon, device such as semi-conductor element is manufactured. According to the method for producing the semi-conductor device described above, the semi-conductor device having micro circuit pattern may be obtained with high throughput.

[00117] Further, in the exposure device shown in Figs. 1 to 9, liquid crystal display as a micro device may be attained by forming predetermined patterns (circuit pattern, electrode pattern, etc.) on a plate (glass substrate). Now, an example of this process will be described with reference to a flow chart in Fig. 11. In Fig. 11, the pattern forming process (step 401), so-called a photo lithography process, is carried out in which patterns of the reticle are exposed and transferred to the photosensitive substrate (e.g., glass substrate covered with resist and etc.) using the exposure device of this embodiment. Predetermined patterns with many electrode and others are formed on the photosensitive substrate by said photo lithography process. Then, the development, etching, reticle, and stripping are carried out on the exposed substrate, so that the predetermined patterns are formed on the substrate and it moves to a color filter forming process (step 402).

[00118] During the color filter forming process (step 402), the color filter is formed, wherein many sets of three dots corresponding to R(Red), G(green), and B(blue) are arranged in matrix. After the color filter forming process (step 402), a cell assembly process (step 403) is carried out after the color filter forming process (step 402). In the cell assembly process (step 403), the liquid crystal display panel is assembled by assembling the substrate having predetermined pattern formed in the pattern forming process (step 401), the color filters formed in the color filter forming process (step 402) and so on. In the cell assembly process (step 403), liquid crystal is injected between the substrate having predetermined pattern formed in the pattern forming process (step 401) and the color filters formed in the color filter forming process (step 402), so that liquid crystal panel (liquid crystal cell) is manufactured.

[00119] Next, in a module assembly process (step 404), each component, such as the electrical circuits, back light, and other is assembled into liquid crystal element, wherein said components are for enabling display operation of the liquid crystal panel (liquid cell) and suitable for assembly. According to the assembly method described above, the liquid crystal display element having extremely fine circuit patterns may be attained with high throughput.

[00120] Further, in the embodiments described above, the diffraction optical element as the light modifying optical system may be configured to be positioned in the optical path of

illumination by a manner such as turret. Also, said diffraction optical element may be inserted, removed, and switched by, for example, the known slider devices. The diffraction optical elements, which may be used in the present invention, are described in US patent 5,850,300 specifically. Further, the wavefront-splitting type optical integrator, for example, a fly's eye lens or micro fly's eye, may also be used, while the diffraction optical element as the light modifying optical system is used in the embodiments described above.

[00121] Further, other suitable optical components such as a fly's eye lens or diffraction optical element may also be used, while a micro fly's eye or rod type integrator is used as multi light source forming means in the embodiment described above. Further, in the first and second embodiments, the illumination region is defined on the predetermined surface conjugated with the mask 10, and the light from this illumination region is limited to the mask blind 8 and passes through the relay optical system 9, so that the illumination region is defined on the mask 10. However, it is also possible that the light passes through the zoom lens 7 or 70 without the relay optical system 9 so that the illumination region is directly formed on the mask 10 positioned on the mask blind 8.

[00122] Further, an annular light enters into the rod type integrator having a rectangular shaped cross section in the third embodiment, but it is preferred that the light is modified to have an elliptical shaped light before such entering. Also, the rod type integrator may be a single glass rod with cavity and may be reflective mirrors assembled in a tunnel shape. In case of forming the rod type integrator with reflective mirror, the size d5 of the cross section thereof may be configured to be variable as desired.

[00123] Further, in the embodiments described above, the aperture stop is disposed adjacent to rear focal surface of the micro fly's eye to limit light from the secondary light source. In some cases, however, by making a cross section of each small-sized lens forming the micro fly's eye small sufficiently, light may not be limited while using no aperture stop.

[00124] Further, in the embodiment described above, the example of forming a quadrupole secondary light source is described, but multi-pole shaped secondary light source, for example, dipole or octupole secondary light source, may also be formed. Further, in the embodiment described above, the present invention is described as an example of a projection exposure device with the illumination optical device. However, it is clear that the present invention may also be applied to typical illumination optical system to illuminate the illumination target surfaces other than to mask uniformly.

[00125] Further, in the embodiments, since the light having a wavelength longer than 180nm, such as KrF eximer laser (wavelength: 248nm) or ArF eximer laser (wavelength: 193nm), is used for exposure, the diffraction optical element may be formed with, for example, quartz glass. Further, in case of using the light having a wavelength shorter than 200nm for exposure, it is preferred to form a diffraction optical element with material selected from the group of fluorite, doped quartz glass with fluorine, doped quartz glass with fluorine and hydrogen, quartz glass with structure crystalline at temperature below 1200K and OH

concentration above 1000ppm, quartz glass with structure crystalline at temperature below 1200K and hydrogen molecule concentration above $1x10^{17}$ molecule/cm^3, quartz glass with structure crystalline at temperature below 1200K and chlorine concentration below 50ppm, and quartz glass with structure crystalline at temperature below 1200K, hydrogen molecule concentration above $1x10^{17}$ molecule/cm^3 and chlorine concentration below 50ppm.

[00126] Quartz glass with structure crystalline at temperature below 1200K and OH concentration above 1000ppm is disclosed in Japanese Patent No. 2770224 of the present applicant. Quartz glass with structure crystalline at temperature below 1200K and hydrogen molecule concentration above $1x10^{17}$ molecule/cm^3; quartz glass with structure crystalline at temperature below 1200K and chlorine concentration below 50ppm; and quartz glass with structure crystalline at temperature below 1200K and hydrogen molecule concentration above $1x10^{17}$ molecule/cm^3 and chlorine concentration below 50ppm are disclosed in Japanese Patent No. 2936138 of the present applicant.

Effects of the Invention

[00127] As described above, in the illumination optical apparatus of the present invention, the illumination NA and the size of the illumination region may be adjusted to a desired value, while avoiding light loss by controlling the focal length or the magnification of the first variable magnification optical system and second variable magnification optical system. Thus, in the exposure apparatus with the illumination optical apparatus of the present invention, the size of the exposure region and the σ value may be adjusted to a desired value, respectively, while reducing light loss in the aperture stop or the illumination field stop. As a result, the exposure apparatus of the present invention is configured to set the size of the illumination region (exposure region) and the σ value to the optimized value according to the property of the micro device to be manufactured, and thereby preferably providing exposure with high throughput based on high illuminance for exposure and desirable exposure conditions.

[00128] Further, the exposure method, which exposes the mask pattern displaced on the illumination target surface onto the photosensitive substrate, and the manufacture method for micro devices may perform the projection exposure based on a preferable exposure condition, and thereby, the desired micro devices can be manufactured. Further, according to the typical embodiment of the present invention, the modified illumination, such as the annular illumination or quadrupolar illumination, and the conventional circular illumination may be formed, while reducing light loss in the aperture stop for limiting the secondary light source. Thus, in the exposure apparatus with the illumination optical apparatus of the present invention, the resolution and the depth of focus suitable for micro pattern to be exposed may be obtained by adjusting the type of the modification illumination. As a result, preferable exposure with high throughput may be performed based on the high exposure illuminance and desired exposure conditions.

[00129] The adjusting means allows for the illumination numerical aperture to be adjusted, even when the illumination numerical aperture has been changed by converting the light for exposure into the light having desired light intensity distribution by light converting means (changing means). Therefore, the exposure apparatus and the manufacturing method for micro devices for preferably exposing the mask pattern on the photosensitive substrate such as wafers at all times in accordance with a desired exposure condition or desired illumination condition may be realized.

Brief Description of the Drawings

Fig. 1 schematically shows a configuration of a device comprising an illumination optical apparatus according to a first embodiment of the present invention.
Fig. 2 is a perspective view illustrating an internal configuration and operation of a light delay part 2 in FIG. 1.
Fig. 3 shows a relationship between focal lengths of a zoom lens 4 and a zoom lens 7; and an illumination NA and a size of a rectangular illumination region formed in a predetermined surface that conjugates with a mask 10 in the first embodiment.
Fig. 4 shows an operation of a diffraction optical element 3a for annular illumination.
Fig. 5 shows an operation of a diffraction optical element 3b for quadrupolar illumination.
Fig. 6 schematically shows a configuration of an exposure apparatus with an illumination optical apparatus according to a second embodiment of the present invention.
Fig. 7 shows a relationship between focal lengths of a zoom lens 4 and a micro fly's eyes group 50; and an illumination NA and a size of a rectangular illumination region formed in a predetermined surface that conjugates with a mask 10 in the second embodiment.
Fig. 8 schematically shows a configuration of an exposure apparatus with an illumination optical apparatus according to a third embodiment of the present invention.
Fig. 9 shows a relationship between magnifications of a zoom lens 41 and a zoom lens 71; and an illumination NA and a size of a rectangular illumination region formed in a predetermined surface that conjugates with a mask 10 in the third embodiment.
Fig. 10 is a flow chart of an example method for obtaining a semiconductor device as a micro device.
Fig. 11 is a flow chart of an example method for obtaining a liquid crystal display element as a micro device.

<Descriptions of Reference Numerals for Primary Parts of the Drawings>
1: Light Source
2: Light Delay Part
3: Diffraction Optical Element
4: Zoom Lens
5: Micro Fly's Eye
6: Aperture Stop
7: Zoom Lens

8: Mask Blind
9: Relay Optical System
10: Mask
11: Projection Optical System
12: Wafer
13: Wafer Stage
20: Input Means
21: Control System
22 ~ 25: Drive System

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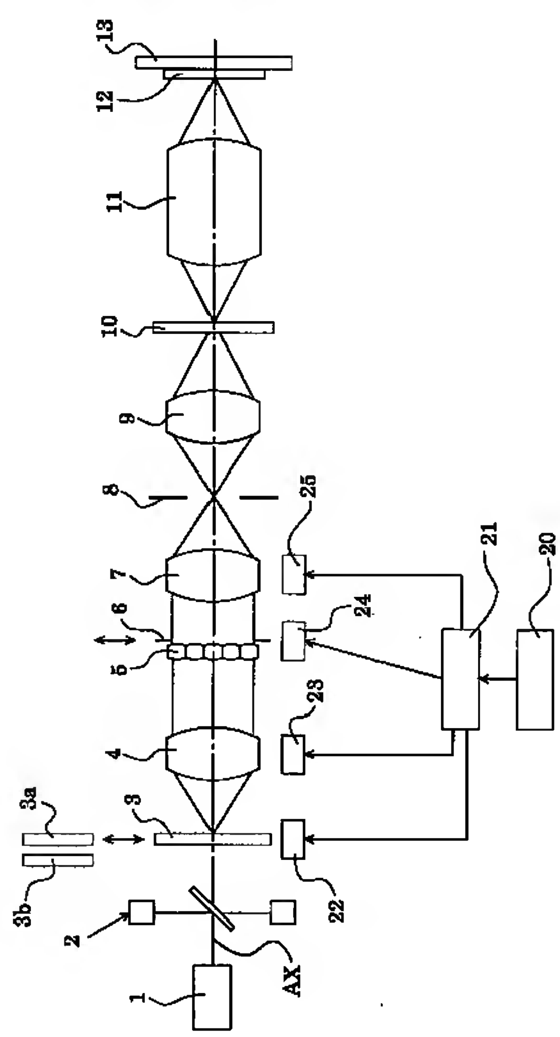

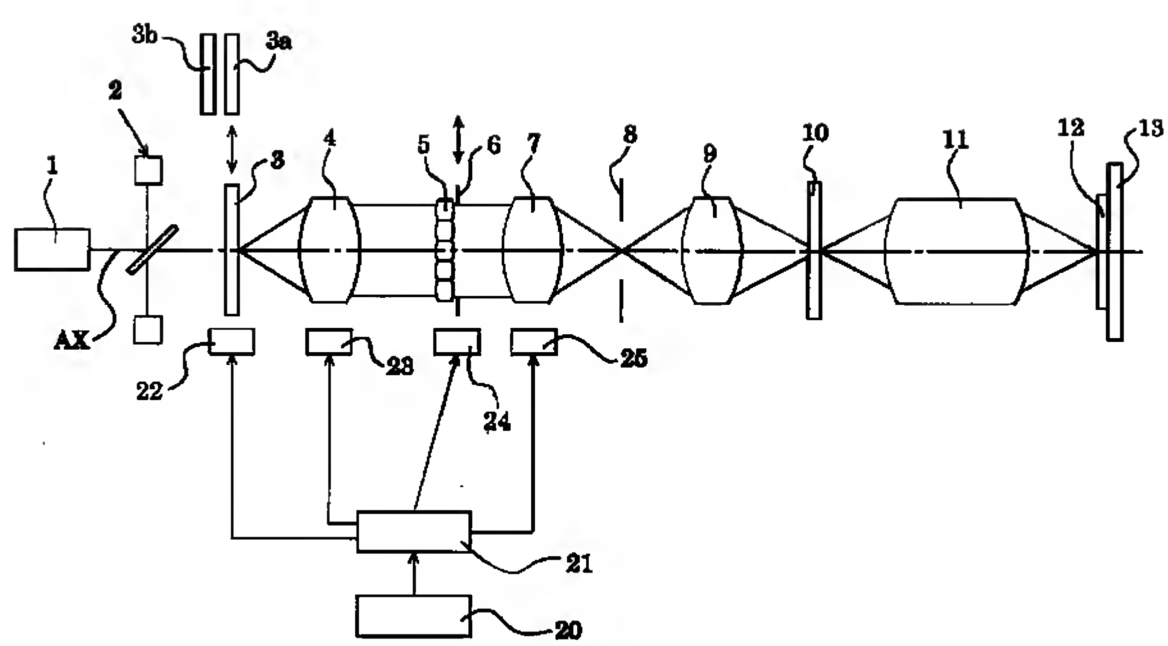

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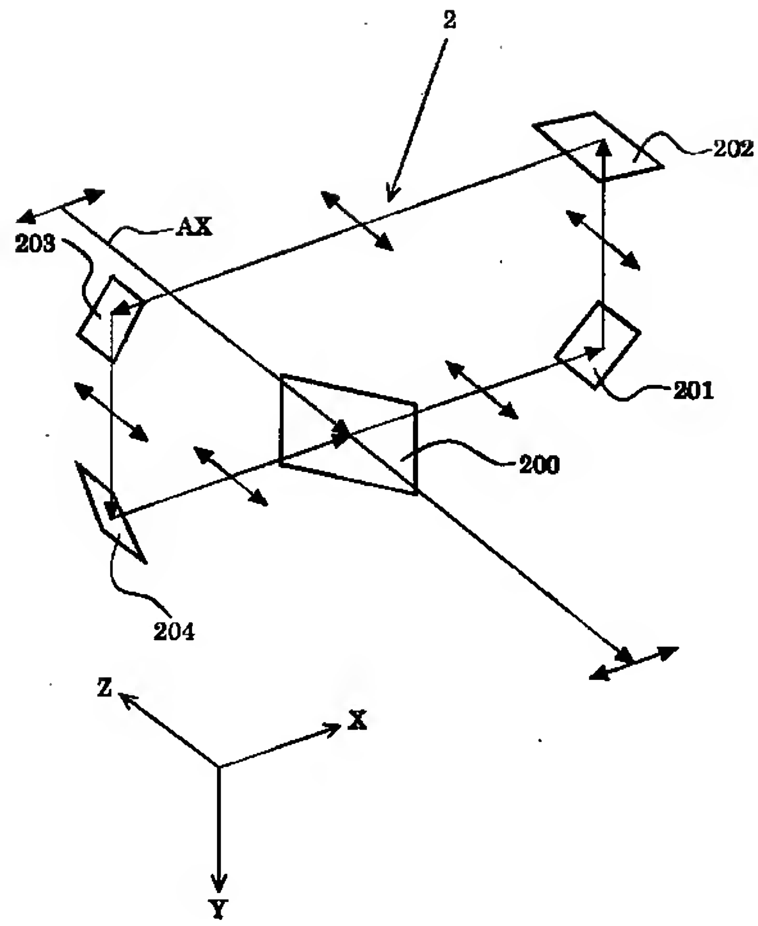
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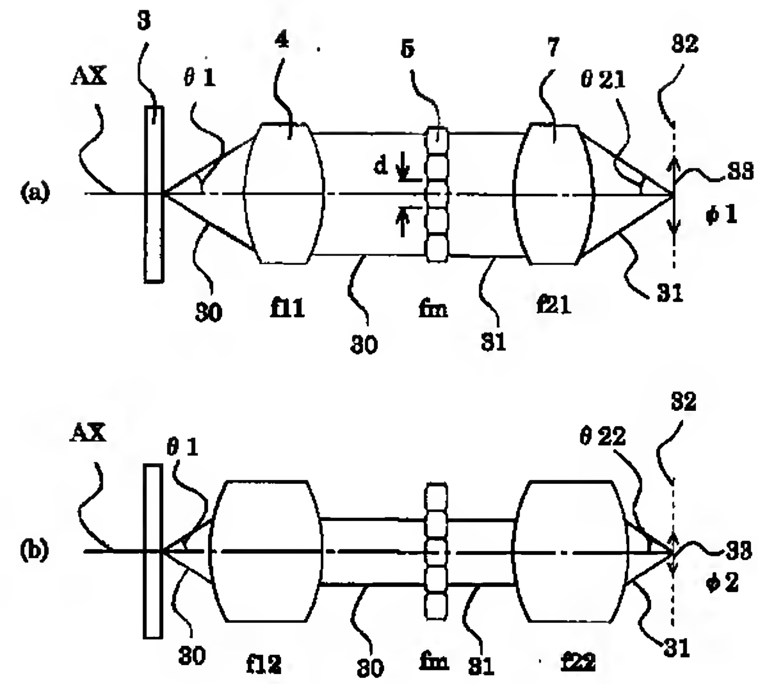
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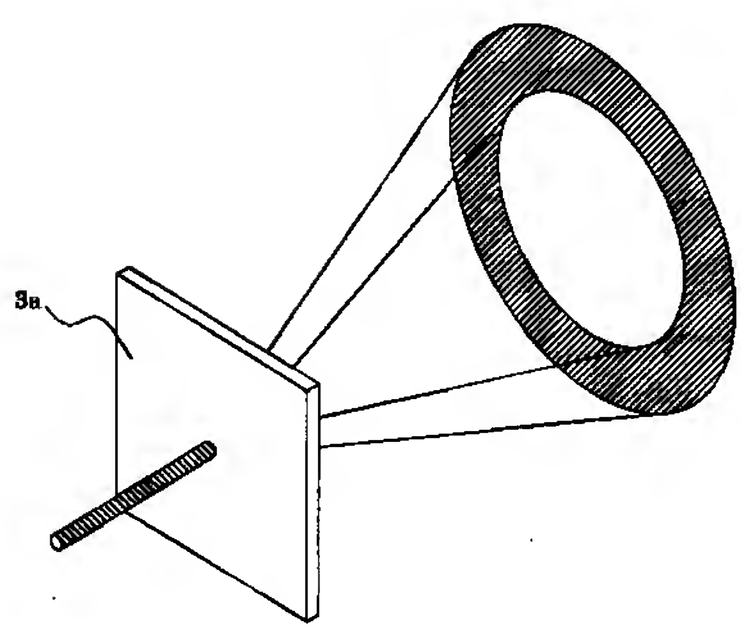
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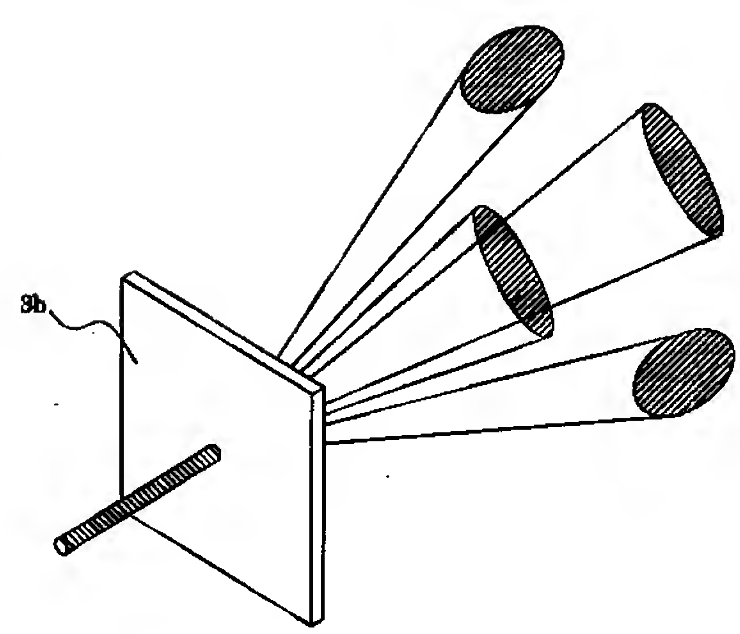
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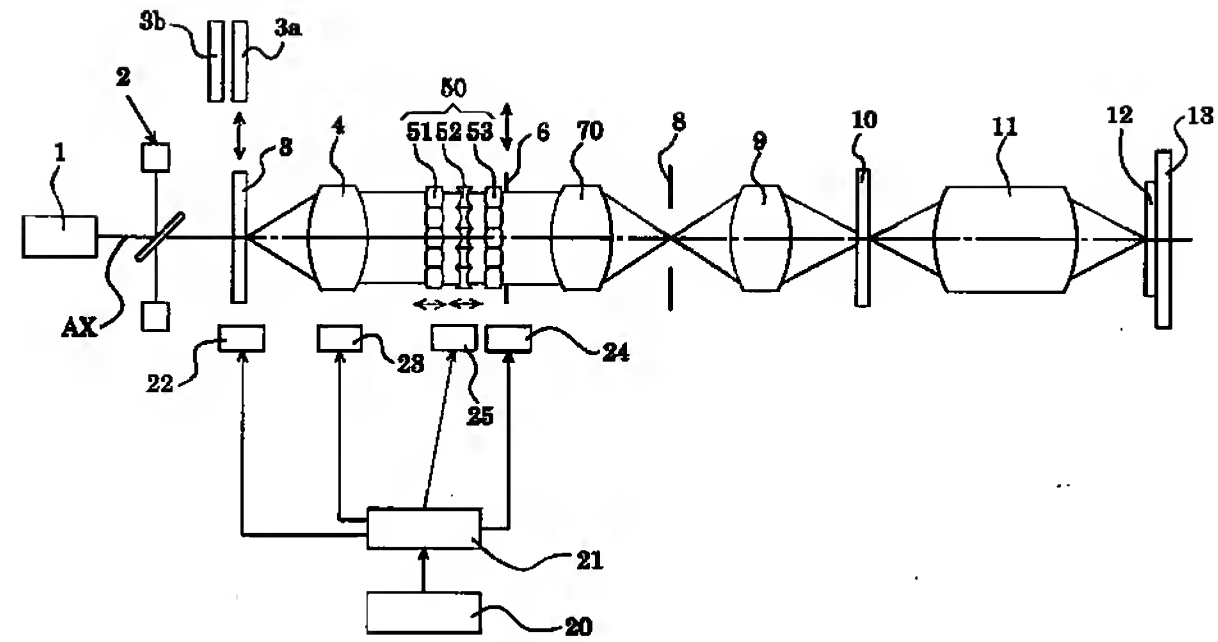
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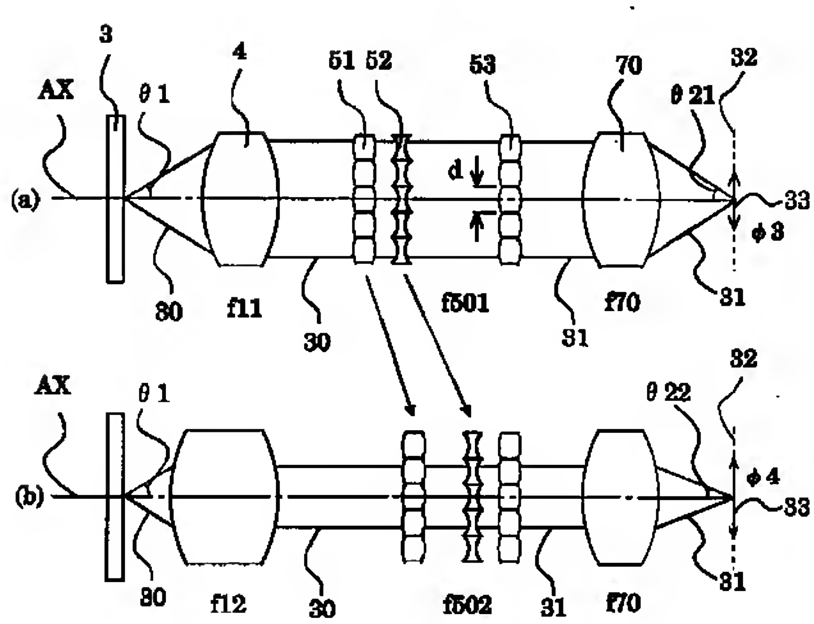
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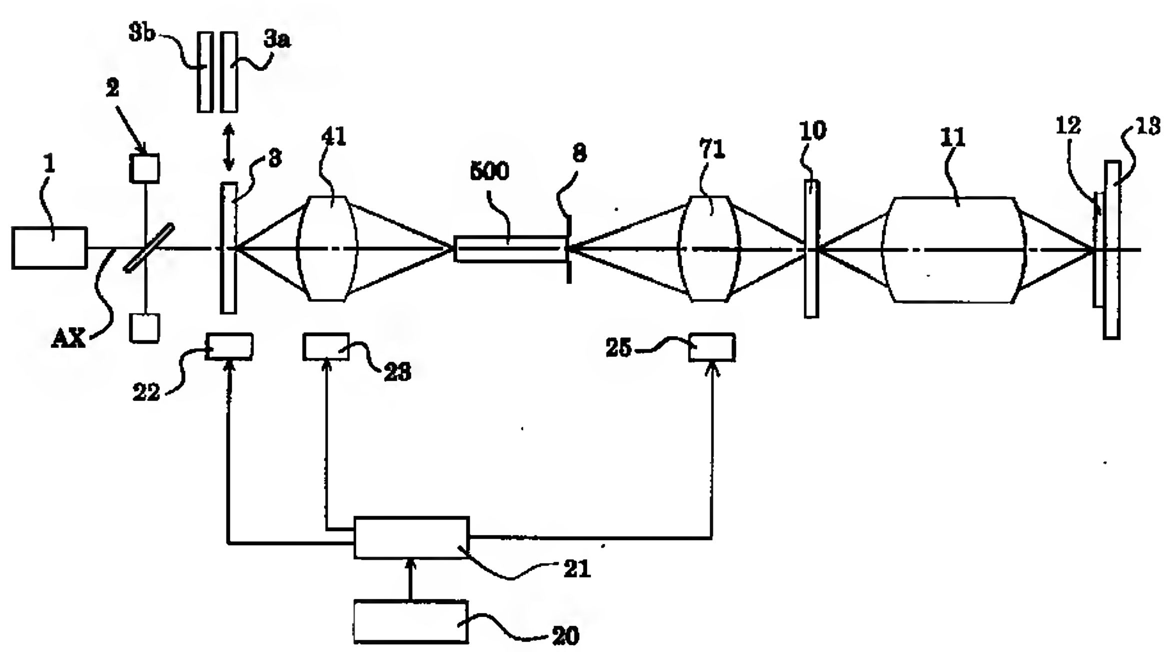
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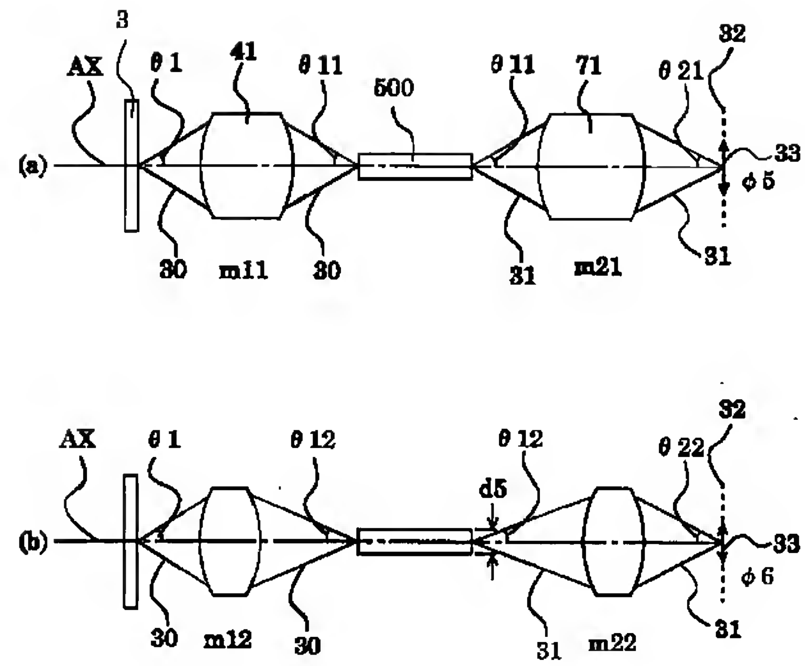
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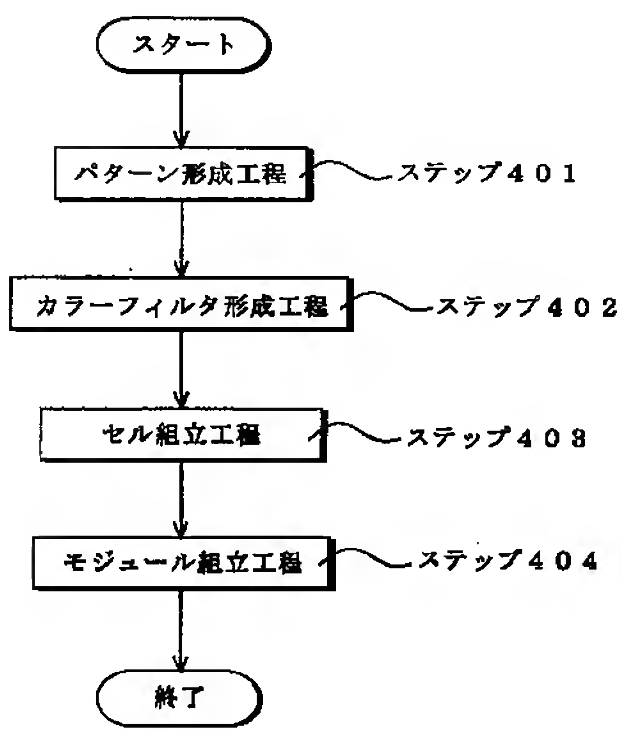
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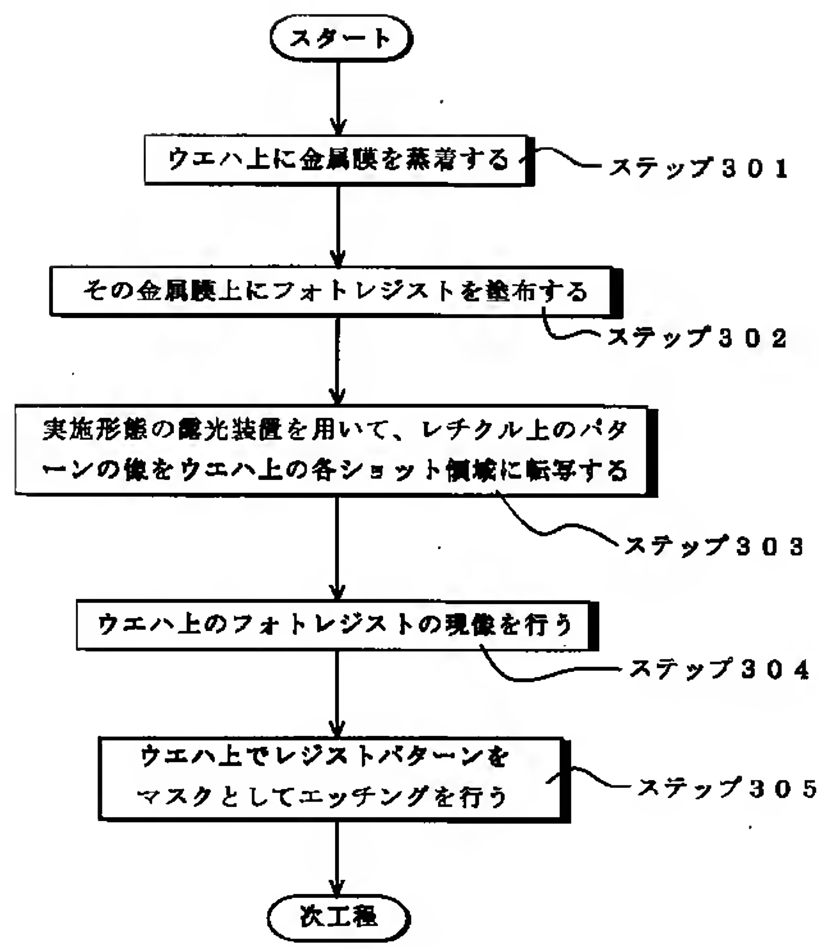
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その金属膜上にフォトレジストを塗布する
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実施形態の露光装置を用いて、レチクル上のパターンの像をウエハ上の各ショット領域に転写する
ステップ３０３
ウエハ上のフォトレジストの現像を行う
ステップ３０４
ウエハ上でレジストパターンをマスクとしてエッチングを行う
ステップ３０５
次工程